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ABSTRACT

Most of the regional shortening in the type area of the Sevier orogenic belt in central Utah was accommodated by displacement on the Canyon Range (Neocomian-Aptian), Pavant (Aptian-Albian), Paxton (Cenomanian-Campanian), and Gunnison (late Campanian–Paleocene) thrust systems. Inception of each thrust system generated synorogenic sediment associated with frontal thrust-tip anticlines or triangle zones and older thrust sheets that were elevated above major ramps farther toward the hinterland. The Sevier culmination, a large antiformal duplex cored by crystalline basement rocks, developed during Paxton and Gunnison thrusting west of and structurally beneath the Canyon Range and Pavant thrusts. Growth of the Sevier culmination was coeval with reactivation of the Canyon Range and Pavant thrust systems and produced a second culmination in Proterozoic–Lower Cambrian rocks in the Canyon Range. These structural highs provided much of the sediment to the adjacent foreland basin from late Cenomanian to late Paleocene time, and may have helped to maintain critical taper in the thrust belt.

INTRODUCTION

The Sevier fold-thrust belt in the North American Cordillera is one of the most important thrust belts in the world, both because of its large scale and because it has been the source of many general principles of thrust belt geology (e.g., Armstrong, 1968; Dahlstrom, 1970; Royse et al., 1975). Ironically, where Armstrong (1968) first recognized the large scale of Sevier thrust faulting in central Utah, no consensus exists regarding the kinematic history of thrusting (e.g., Lawton, 1985; Villien and Kligfield, 1986; Yingling and Heller, 1992). This paper presents a revised scheme of thrust timing for central Utah, based mainly on recent work in the Canyon Range (Pequera et al., 1994; Mitra et al., 1994; DeCelles et al., 1995), previous and recent studies in the San Pitch Mountains (also referred to as the Gunnison Plateau; Lawton, 1982, 1985, 1986; Lawton et al., 1993), and regional seismic and structural data (Standlee, 1982; Allmendinger et al., 1983, 1986; Royse, 1993; Coogan et al., 1995). Our results indicate that an overall eastward progression of frontal thrusting was accompanied by hindward thrust reactivation and growth of large structural culminations that profoundly influenced regional subsidence, sediment supply, and thrust-belt taper.

GEOLOGIC AND STRUCTURAL SETTING

A west-to-east transect through central Utah crosses several important Mesozoic and Cenozoic structures (Fig. 1). The Confusion Range synclinorium and House Range constitute a large synform-antiform pair that developed above a major thrust ramp in the hinterland of the Sevier belt (Hose, 1977; Allmendinger et al., 1983). Allmendinger et al. (1986) interpreted antiformal reflectors in basement rocks beneath the House Range as a large duplex produced during Sevier thrusting. East of the House Range lies the Sevier Desert basin, a large Tertiary basin underlain by the Sevier Desert detachment fault (McDonald, 1976; Allmendinger et al., 1983). Although the existence of the detachment beneath the southern Sevier Desert has been questioned (Anders and Christie-Blick, 1994), regional seismic and geologic data confirm its presence throughout the area discussed in this paper (Coogan et al., 1995). Restoration of 35 km of down-to-the-west displacement (Allmendinger et al., 1986) on the detachment brings the eastern limb of the basement duplex beneath the House Range to within a few kilometres of the Canyon Range. We refer to this broad antiform as

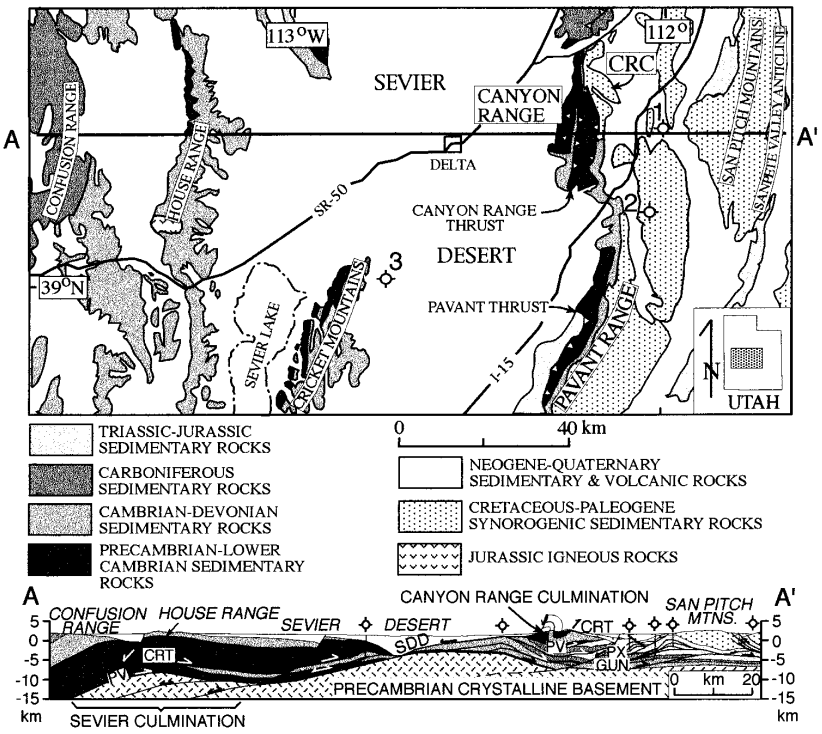

Figure 1. Generalized geologic map of central Utah, after Hintze (1980). Inset shows location of map area in Utah. Boreholes: 1—Placid WXC Barton 1; 2—Placid WXC USA 1-2; 3—Cominco American #2 Beaver River. CRC indicates Canyon Range Conglomerate. Line A-A shows trace of regional geologic cross section (below), after Coogan et al. (1995). Major structures: CRT—Canyon Range thrust; PV—Pavant thrust; SDD—Sevier Desert detachment fault; PX—Paxton thrust; GUN—Gunnison thrust.

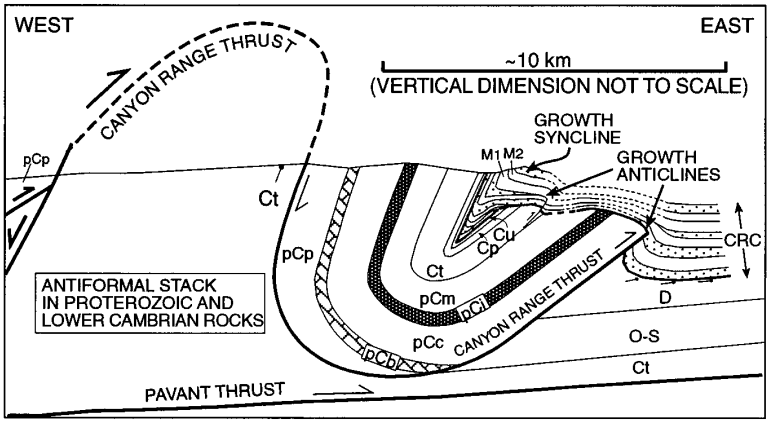

Figure 2. Schematic, composite cross section through northern Canyon Range, showing relations between Canyon Range thrust, antiformal stack exposed in structural window, and Canyon Range Conglomerate (CRC). Stippled units in conglomerate are quartzite petrofacies; unpatterned units are carbonate and mixed (M1, M2) petrofacies. Stratigraphic units: pCp—Pocatello Group; pCb—Black Rock Limestone; pCc—Caddy Canyon Formation; pCi—Inkom Formation; pCm—Mutual Formation; Ct—Tintic Formation; Cp—Pioche Formation; Cu—Cambrian undivided (mainly limestone); O-S—Ordovician and Silurian carbonates and siliciclastics; D—Devonian carbonates.

the Sevier culmination, after the regional late Mesozoic paleogeographic high that Harris (1959) named the "Sevier arch." Four major thrust systems, accommodating at least 120 km of east-west shortening, constitute the Sevier belt in central Utah (Fig. 1): the Canyon Range, Pavant, Paxton, and Gunnison thrusts (Standlee, 1982; Villien and Kligfield, 1986; Royse, 1993). Because of its importance for regional kinematic interpretations, the structure of the Canyon Range is discussed in more detail below.

The Canyon Range is dominated by the Canyon Range thrust sheet and a large, truncated, structural window through the thrust in the western part of the range (Christiansen, 1952; Holladay, 1983). The thrust is folded into an eastward-verging antiform-synform pair; the western limb of the antiform is truncated by Tertiary normal faults (Fig. 2). The structure in the window is an antiformal stack (Sussman and Mitra, 1995). In the east limb of the antiform, the thrust dips ~55° eastward in the southern part of the range (Millard, 1983), but steepens northward and is overturned, dipping ~80° westward in the northern part of the range (Fig. 2; Holladay, 1983). Along the east limb of the antiform, the fault places Proterozoic strata on top of complexly deformed Lower Cambrian Tintic quartzite and Cambrian-Ordovician carbonate rocks in the structural window. The Canyon Range thrust was folded by growth of the footwall antiformal stack exposed in the window, which produced a second culmination referred to as the Canyon Range culmination (Fig. 1). Along its frontal trace, the thrust dips ~40° westward and juxtaposes a hanging wall flat, beneath Proterozoic Caddy Canyon quartzite, with a footwall ramp that cuts Cambrian, Silurian, and Devonian strata, and ~300 m of the Upper Cretaceous Canyon Range Conglomerate (Fig. 2). The frontal trace of the fault is overlapped in its northern part by the upper part of the Canyon Range Conglomerate.

CANYON RANGE CONGLOMERATE

The Canyon Range Conglomerate is 500–700 m thick and crops out extensively in the northern Canyon Range (Christiansen, 1952). It contains a quartzitic petrofacies composed of clasts from the Caddy Canyon, Mutual, Tintic, and Pioche Formations (Proterozoic–Lower Cambrian); a carbonate petrofacies composed of limestone, dolomite, sandstone, and siltstone clasts derived from Cambrian through Devonian rocks; and a mixed petrofacies containing quartzite, carbonate, siltstone, and sandstone clasts.

The quartzite petrofacies consists of proximal alluvial-fan deposits. The carbonate petrofacies is mainly fluvial deposits, with a ~10 m thick unit of marine fan-delta deposits in the lowest carbonate petrofacies unit. The mixed petrofacies consists of distal alluvial-fan and fluvial deposits. In the core of the Canyon Range syncline, the conglomerate is incorporated into a north-northeast–plunging growth syncline, the limbs of which flatten gradually upsection (Fig. 2). Growth anticlines in the conglomerate are present along the east side of the range and on the upper part of Fool Creek Peak (Fig. 2). The Canyon Range Conglomerate is Late Cretaceous in age, on the basis of sparse fossils and regional lithostratigraphic correlation (Christiansen, 1952; Armstrong, 1968; Stolle, 1978). Correlation of the marine fan-delta facies in the lower part of the conglomerate with pollen-bearing marginal marine units in the Placid WXC USA 1-2 well (sec. 24, T.19 S., R.2 W.) and the Placid WXC Barton 1 well (sec. 32, T. 16 S., R. 1 W.) to the east of the Canyon Range (Villien and Kligfield, 1986) suggests a late Cenomanian–Turonian age. From Santonian time onward, central Utah was occupied by fluvial and local lacustrine systems (Lawton, 1985). A *tentative* Campanian-Paleocene age for the upper part of the Canyon Range Conglomerate is suggested by correlation with the Campanian-Paleocene North Horn Formation in the San Pitch Mountains (Lawton, 1986; Lawton et al., 1993).

CONGLOMERATE UNITS IN THE SAN PITCH MOUNTAINS

Three conglomeratic units in the San Pitch Mountains (Fig. 1) provide information about the regional timing of Sevier thrust faulting. These include the Cedar Mountain Formation (Lower Pigeon Creek Formation of Schwans, 1988), the Indianola Group, and the North Horn Formation. Ages of these units are based on palynologic and magnetostratigraphic data and on regional lithostratigraphic correlations (Spieker, 1946; Standlee, 1982; Schwans, 1988; Weiss and Roche, 1988; Sprinkel et al., 1992; Lawton et al., 1993; Talling et al., 1994). In the western San Pitch Mountains, the upper Neocomian–Aptian (Weiss and Roche, 1988; Sprinkel et al., 1992) Cedar Mountain Formation consists of ~150 m of chert-rich fluvial sandstone and conglomerate, overbank mudstone, and local lacustrine limestone. These rocks are overlain by the Aptian–late Albian (Sprinkel et al., 1992) upper member of the Pigeon Creek Formation (Schwans, 1988) or the San Pitch Formation (D. A. Sprinkel, personal commun.), which consists of ~150–800 m of alluvial-fan and related fluvial deposits (Lawton, 1985; Schwans, 1988). San Pitch conglomerates contain clasts of Proterozoic–Lower Cambrian quartzite, lower and middle Paleozoic carbonate and siliciclastic rocks, and Jurassic sandstone (Lawton, 1986; Schwans, 1988; Sprinkel et al., 1992).

The Indianola Group in the San Pitch Mountains is Albian–late Campanian in age, ~2 km thick, and consists of fluvial and deltaic sandstone and conglomerate and shallow-marine sandstone and siltstone (Lawton, 1985). Conglomerates low in the section contain Paleozoic carbonate, Proterozoic quartzite, and Jurassic sandstone clasts. Conglomerates in the upper part of the Indianola are dominated by quartzite clasts of the Proterozoic-Cambrian Mutual and Tintic Formations (Lawton, 1985, 1986).

The North Horn Formation in the San

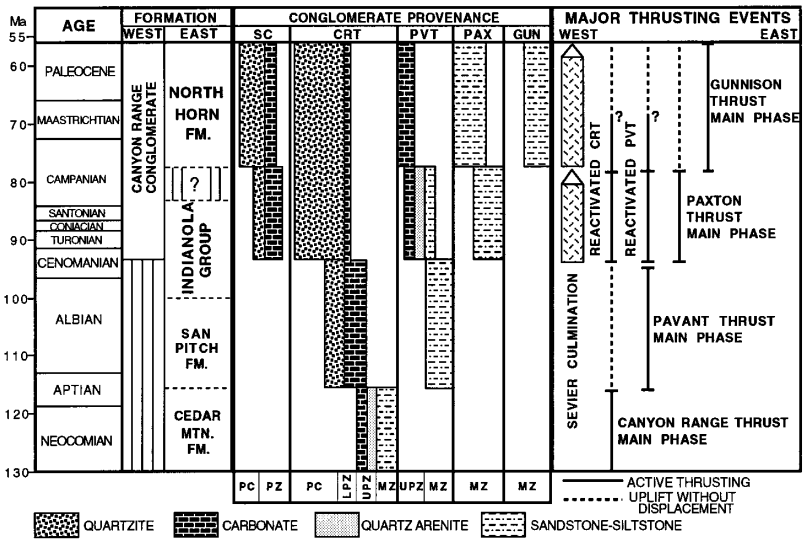

Figure 3. Chart depicting provenance of Cretaceous-Paleocene conglomeratic units and proposed sequence of Sevier thrust faulting in central Utah. Conglomerate provenance panel shows likely source stratigraphic units (ages of units are along bottom of panel) and lithologies (shown by various patterns) divided among five principal source terranes: SC—Sevier culmination; CRT—Canyon Range thrust sheet; PVT—Pavant thrust sheet; PAX—Paxton thrust sheet; GUN—Gunnison thrust sheet. Ages of conglomerate source-rock units are abbreviated as follows: PC—Proterozoic; PZ—Paleozoic; LPZ—lower Paleozoic; UPZ—upper Paleozoic; MZ—Mesozoic.

Pitch Mountains is late Campanian–Paleocene and consists of 42–1100 m of alluvial-fan, fluvial, and lacustrine deposits. North Horn conglomerates contain Precambrian and Lower Cambrian quartzite and Paleozoic carbonate clasts as well as clasts reworked from the Indianola Group and underlying Mesozoic rocks (Lawton, 1986; Lawton et al., 1993).

CONGLOMERATE PROVENANCE AND THE HISTORY OF SEVIER THRUSTING

The regional provenance of conglomerate units can be depicted in terms of five potential source terranes (Fig. 3): those toward the hinterland, including the Canyon Range thrust sheet and Sevier culmination, and those in the frontal part of the thrust belt, including frontal antiformal ridges associated with the Pavant, Paxton, and Gunnison thrusts. The first major episode of thrusting clearly recorded by Cretaceous sedimentary rocks was during late Neocomian time, when the Canyon Range thrust sheet was displaced ~40–70 km eastward (Royse, 1993; Coogan et al., 1995). The red siltstone and chert-rich sandstone and conglomerate of the Cedar Mountain Formation were derived from Mesozoic and middle-upper Paleozoic strata uplifted on the Canyon Range sheet (Yingling and Heller, 1992; Currie, 1995). Initial Pavant thrusting is indicated by the ensuing Aptian-Albian San Pitch Formation, which was derived from lower Paleozoic carbonates and Late Proterozoic–Cambrian age quartzites on the Canyon Range sheet. In addition, minor amounts of Jurassic sandstone clasts and abundant frosted (eolian) sand grains in the San Pitch Formation were derived from the Jurassic Navajo and Twist Gulch Formations. The mixture of friable Jurassic clasts and durable lower Paleozoic–Proterozoic clasts was produced by contributions from both the Canyon Range sheet, which was uplifted in the hanging wall of the Pavant thrust, and a frontal anticlinal ridge that developed above the propagating Pavant thrust tip. Pavant thrusting probably continued sporadically until Cenomanian time.

Paxton thrusting initiated growth of the Sevier culmination during Cenomanian time, producing a major topographic plateau that supplied much of the sediment to the foreland basin through Paleocene time. This is based on the interpretations of Allmendinger et al. (1983, 1986) and Royse (1993) that the Canyon Range and Pavant thrusts are folded above the culmination, whereas the Paxton thrust is beneath it. Along the east side of the Sevier culmination, the rear part of the Pavant sheet was reactivated, producing the antiformal stack in the Canyon Range culmination and tightening folds in the Canyon Range thrust sheet. The frontal part of the Canyon Range thrust also was reactivated, perhaps by flexural slip during folding of the thrust sheet. The growth folds in the Canyon Range Conglomerate indicate deposition coeval with growth of the Canyon Range culmination and reactivation of the Canyon Range thrust. The relatively fine grained, fluvial and marginal-marine carbonate-clast conglomerates in the Canyon Range Conglomerate were derived from the crest of the Sevier culmination, which was not eroded below the level of Cambrian carbonates, whereas the proximal alluvial-fan quartzitic conglomerates were derived from the growing Canyon Range culmination. Eventually, the antiformal stack in the footwall of the Canyon Range thrust was erosionally breached, providing large amounts of Tintic quartzite clasts, in addition to the Caddy Canyon and Mutual clasts derived from the Canyon Range sheet.

Contemporaneous Indianola Group strata exhibit a similar sequence of clast compositions; Paleozoic carbonate-rich conglomerate gives way upsection to dominantly Proterozoic quartzitic conglomerate (Fig. 3). The persistence of friable Jurassic sandstone and limestone clasts in the Indianola Group probably indicates local sources in the frontal Paxton thrust sheet.

Late Campanian–Paleocene Gunnison thrusting is indicated by progressive deformation in North Horn strata along the frontal triangle zone of the thrust (Talling et al., 1994). Further growth and erosion of the Sevier and Canyon Range culminations maintained the supply of Proterozoic quartzite and lower Paleozoic carbonate clasts to the upper Canyon Range Conglomerate and North Horn Formation. At the same time, relatively young clasts were derived from frontal thrust ridges of the Paxton and Gunnison thrusts (Fig. 3).

CONCLUSIONS

The sequence of thrusting proposed above (Fig. 3) is similar to that documented in the Sevier belt of northern Utah, Idaho, and southwestern Wyoming (summarized in DeCelles, 1994). In both areas, an overall eastward progression was punctuated by out-of-sequence reactivation events and the long-term supply of sediment was dominated by a large structural culmination cored by Precambrian basement rocks toward the hinterland. Similar basement culminations are present in many thrust belts, such as the Alps (Pfiffner, 1986; Schönborn, 1992), Appalachians (Boyer and Elliott, 1982), Himalayas (Schelling, 1992; Srivastava and Mitra, 1994), and Pyrenees (Munoz, 1992). In addition to dominating the supply of detritus to the adjacent foreland basin, these large culminations probably control the distribution of flexural foreland subsidence and may develop as a means of maintaining critical taper in the orogenic wedge, allowing it to propagate forward into thin cover sections over long time spans (e.g., DeCelles and Mitra, 1995).

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